Determination of Airflow Distributions in Okaba Underground Coal Mine

[1]Jide Muili Akande, [2] Moshood Onifade, [3] Adeyemi Emman Aladejare

[1,2,3] Department of Mining Engineering, Federal University Of Technology Akure, Ondo State, Nigeria

E-mail: akandejn@yahoo.com; moshoodonifade@yahoo.com; adeyemialadejare@yahoo.com

Abstract

The assumption on the design for the mine airflows is that the frictional factor for the entry is 0.0028 Ns^2/m^4 (for smooth pipe), the entry cross section is 0.899 m^2, the entry perimeter is 3.36 m, the modelled pillar is maintained at a fixed length and the diameter of the duct 1.07 m while other parameters like the air volume, length of road way and the pillar width are varied. The design for the pre-ventilation system of the Okaba Coal deposit requires 145 m^3/s of air with a main fan pressure of 2.73 kPa and four booster fans of air volume; 110 m^3/s, 125 m^3/s, 95 m^3/s, 105 m^3/s whose fan pressure are 0.63 kPa, 0.87 kPa, 0.47 kPa, 0.50 kPa respectively, with exhaust fan of 70 m^3/s at fan pressure of 0.38 kPa which is required to ventilate the mine.

Keywords

Mine Airflows; Frictional Factor; Modelled Pillar; Pre-ventilation System; Booster Fan; Exhaust Fan; Fan Power

Introduction

Mining ventilation is an interesting example of a large scale system with significant environmental impact. Indeed, one of the top objectives of modern mining industry is to fulfil ecological specifications during the ore extraction and ore crushing, by optimizing the energy consumption or the production of polluting agents. This motivates the development of new control strategies for large scale aerodynamic processes based on appropriate automation and the consideration of the global system (Marx *et al.,* 2001). The approach presented in this research is focused on the mining ventilation process, as 50 % of the energy consumed by ore extraction goes into ventilation (including heating the air). It is clear that investigating automatic control solutions and minimizing the amount of pumped air to save energy consumption (proportional to the cube of airflow quantity) are of great environmental and industrial interest.

The mine ventilation topology is depicted in Figure 1 is achieved by a turbine and a heater connected on the surface to a deep pit (vertical shaft) that conducts the airflow to the extraction levels. The heater is introduced (in winter time at least) to avoid freeze in the upper part of the shaft and the air is cooled down at high depths (more than 1000 meters) because of the geothermal heating effect (Hinsley, 2005). From the deep pit, fans located at each extraction level pump fresh air to the extraction rooms via tarpaulin tubes. Air with poor quality is naturally driven by the pressure gradient and flows from the extraction rooms back to the exhaust ventilation shaft (similar but separate from the inflow ventilation shaft).

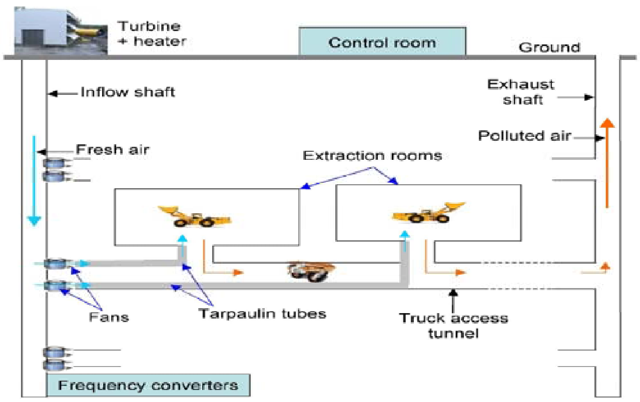

FIG. 1 AIRFLOW IN AN UNDERGROUND MINE (AFTER HINSLEY, 2005)

Methods of Estimating Mine Airflow Requirements

The primary ventilation system, a major contributor to the capital and operating cost of most mines, has a major bearing on the health and safety of the workforce. Probably the most important single design parameter for the primary ventilation system is the overall airflow requirement and errors resulting from the establishment of this value have a wide variety of domino effects on other aspects of the mine design. There are a variety of methods to estimate primary airflow requirements in a mine (Wallace *et al.,* 2008) including:

(a). benchmarking against operations with the same mining method and then pro-rating for different production rates (Calizaya *et al*., 2009);

(b). Ventsim modelling at key, specific milestones in the mine life (Wallace *et al.*, 2008);

(c). manual allocation of airflows to individual activities on individual working levels by month or quarter (or year) for the life of mine (Wallace *et al.*, 2008); and

(d).estimations based on the total diesel engine fleet capacity (kW) and a statutory requirement, such as 0.05 m^3/s per kW of rated engine power (Lang and Ross, 2007). It is very common to find that feasibility studies are based largely or entirely on the last of the above estimation methods.

Fundamentals of Airflow

The quantity of air that will flow through a duct or mine workings is dependent on the difference in pressure at the start and the end of the system, as well as the size of the opening. However, since there are other factors that cause more or less air to flow, the roughness of the wall and the severity and number of times the air has to change direction. When something is moving in a straight line at a constant velocity, energy is required to change the velocity or direction. These changes occur whenever the airway incomplete. The losses in energy due to a change in direction of the airflow are termed "shock pressure losses" (Vutukuri *et al.,* 1998).

Laminar Flow: At low fluid velocities the streamlines of flow are almost parallel to each other. The shear resistance between these streamlines is caused by friction between the layers moving at different velocities. If there is no resistance to movement, the fluid is called frictionless or ideal. If the shear movement is resisted then the fluid is called real. In reality ideal fluids do not exist, however in some cases the resistance is small enough to be insignificant (Hartman *et al.,*2005).

Turbulent flow: As the velocity is increased, the streamlines become randomly arranged and the flow becomes turbulent with the additional eddy currents adding to the shear resistance (Grau, 2002).

Airflow Equation: Investigations undertaken in the 1800's recognised that if there was no pressure difference between the start and end of an airway, there would be no flow of air; i.e. if the pressure was equal to zero, then the quantity of air flowing was also equal to zero. They also recognised that as the pressure was increased then the airflow quantity also increased i.e. the pressure was proportional to the quantity of airflow as expressed in equation 1.

$$R = \frac{P}{Q} \qquad (1)$$

Where

R is Resistance (Ns^2/m^8)

P is Pressure (Pa)

Q is Quantity of airflow (m^3/s)

Resistance to airflow: The resistance to the flow of a fluid in a pipe rises from several sources: (1) viscosity of the fluid (internal friction), (2) friction between the fluid and the pipe internal surface, (3) changes and direction of flow, and (4) obstruction in the path of flow. The pressure loss incurred in overcoming the resistance from the first two sources is friction loss and that in overcoming the last two is shock loss. Friction loss that is the most widely used formula for friction pressure loss in a mine airway is the Atkinson formula

$$H_f = \frac{KLOQ^2}{A^3} \qquad (2)$$

Where H_f is pressure (or head) loss in (Pa)

L is the length of airway in (m)

A is the cross sectional area of airway in (m^2)

O is the perimeter of the airway in (m)

K is the frictional factor in (kg/m3)

The Atkinson friction factor (K) has long been a primary component in calculating airway resistance for ventilation planning purposes and accurate values of friction factor are critical in ventilation planning exercises. No computer simulation is meaningful if the airway resistances throughout a mine are not accurately assessed. For the proposed underground airways, the only way to develop a ventilation model for planning purposes is by means of the estimation of friction factors. For existing underground mines, it is recommended that a proper ventilation survey of the mine ventilation infrastructure be conducted prior to ventilation planning exercises. The determination of frictional pressure drop (p) in mine airways may be obtained from the Equation 2. This is a form of the Chezy-Darcy Equation, applicable to circular and non-circular airways and ducts. The Chezy-Darcy coefficient of friction (dimensionless) varies with

respect to Reynolds Number, the trend of which is plotted on the Moody diagram (Hartman, 2005). The first part of this equation, related to frictional pressure drop and quantity to resistance, known as the Square Law is used to establish resistance from measured pressure and quantity data. The second part of the equation is used to determine resistance from typical Atkinson friction factors, and known or proposed airway geometry. It should be noted that the frictional pressure drop term in the Square Law is directly proportional to air density. Hence, the Atkinson friction factor that is applied must be adjusted for actual mine air density. However, in mine ventilation it is normal to assume that the Atkinson friction factor is relatively constant, regardless of the flow regime. This is because for fully turbulent flow (which is typically the case in mine ventilation) the friction factor is a function only of the relative roughness of the airway (McPherson 1993).

Description Of The Study Area

The study area lies between latitudes 7^0 20^1N and longitudes $7^0 25^1$E and 7^0 45^1E within the tropics and has an average annual rainfall of between 1250 and 1500mm (Iloeje, 1981). The area is accessible through a trunk A road that runs from Ankpa in Kogi State to Markurdi in Benue State. In addition, rural feeder roads and paths enhance accessibility to the surface water and the coalmine. Okaba area consists of lowlands and hills with an average elevation of 274.5m located near the base of the Enugu escarpment. The escarpment is very low and a few kilometres to the south and there is gradual descent from Igala Plateau to the Benue plain, without a break in slope. There are hills that rise up to 335.5m and 244m at the southern part of Okaba and 36m around Odagbo near the coalmine. Geologically, Okaba is underlain by Mamu Formation at the northern, northeastern, northwestern and central parts and Ajali Formation at the southern part. The area is covered by many streams that sometimes originate from caves and often flow down the slope. Most of the streams with many tributaries are characterized with dendritic drainage pattern. The streams density is a function of two major factors. Firstly, the high humid condition which generates a considerable effective rainfall, that fraction of rainfall left over for infiltration or percolation after evaporation has occurred. Secondly, the geology influences the drainage system. The water emerges from the deposits of the Ajali Formation and the Coaliferous aquifers and flow or meander on the shale member of the Mamu Formation.

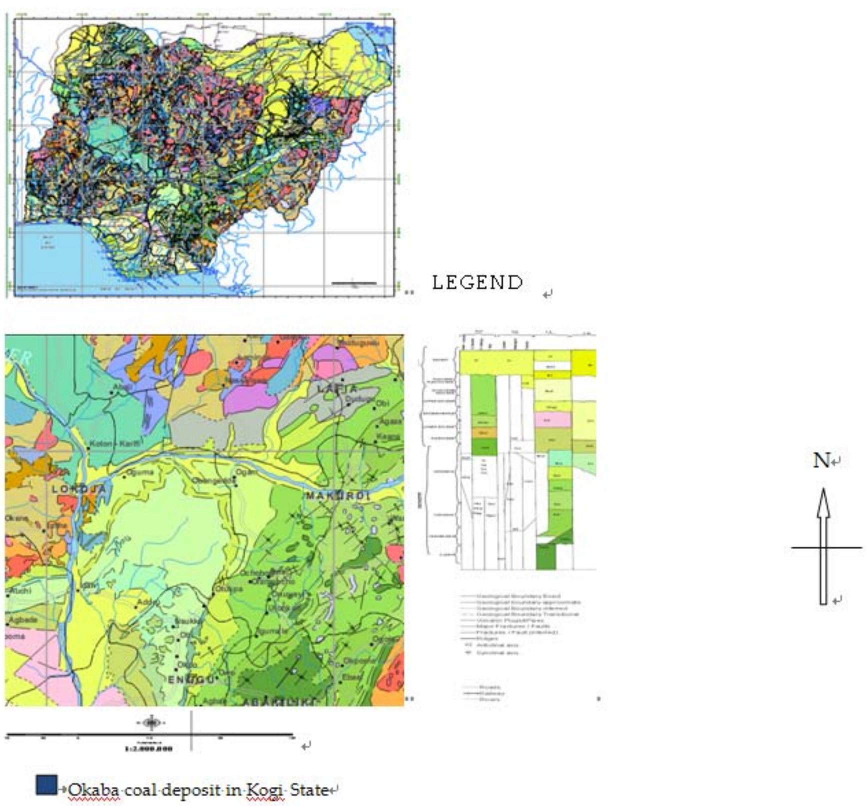

FIG. 2 GEOLOGICAL MAP OF OKABA COAL DEPOSIT EXTRACTED FROM THE GEOLOGICAL MAP OF NIGERIA

Airflow Distribution of Proposed Okaba Underground Coal Deposit

Design values from the equations discussed below were used to design the complete layout of the ventilation system with great attention paid to the ventilation shaft diameter, diameter of the duct, length of opening roadways, dimensions of panel, number of workers, diesel equipment, poisonous gases and targeted production. The assumption of the design is that all the airway types are smooth pipe and the modelled pillar maintained a fixed length while parameters like the pillar width varied in order to generate a factor of safety of 1.6 which is the standard required for safe mining operation in any underground mine. Six fans were installed with one main, one return and the remaining four are booster fans with varying air volume and length of openings basically to determine the mine airflow distribution required for the design with the standard requirement.

The air pressure and the fan power are obtained from equations 3 and 4.

$$P_t = R_d \times Q^2 \text{ (kPa)} \quad (3)$$

$$Fan\ Power = \frac{P_t \times Q}{\eta} \text{(kW)} \quad (4)$$

Where P_t, η and Q is the total air pressure, the efficiency of the fan and Q are the quantity of air respectively.

TABLE 1 MINE AIRFLOW DISTRIBUTION FOR THE PROPOSED

Locations	Fans	Length (m)	Q (m^3/s)	Air Pressure (kPa)	Fan Power (KW)	Duct Resistance (Ns^2/m^8)	Head loss (Ns^2/m^8)
A	1	10	145	2.73	394.70	0.130	2722.33
B	2	4	110	0.63	68.96	0.052	626.68
C	3	4	125	0.81	101.16	0.052	809.25
D	4	4	95	0.47	44.41	0.052	339.96
E	5	4	105	0.57	59.96	0.052	571.00
F	6	6	70	0.38	26.64	0.078	380.67

TABLE 2 DESIGN PARAMETERS FOR PROPOSED OKABA COAL VENTILATION SYSTEM

Fan type	Main Fan	Booster Fan 1	Booster Fan 2	Booster Fan 3	Booster Fan 4	Exhaust Fan
Length (m)	10	4	4	4	4	6
Air volume (m^3/s)	145	110	125	95	105	70
Air Pressure(KPa)	2.73	0.63	0.81	0.47	0.57	0.38
Fan Power(Kw)	394.70	68.96	101.17	44.41	59.96	26.64

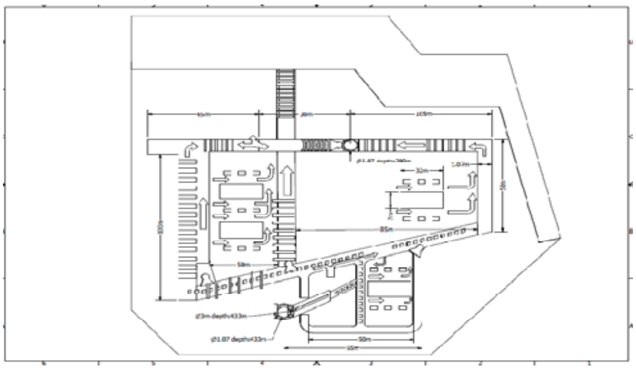

FIG. 3 PLAN VIEW OF PROPOSED OKABA UNDERGROUND COAL

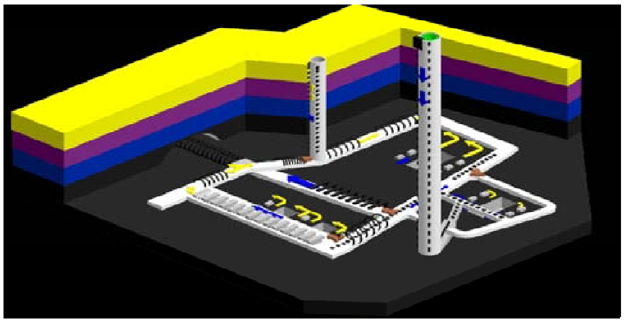

FIG.4 MINE AIRFLOW DISTRIBUTION OF PROPOSED OKABA UNDERGROUND COAL MINE.

Discussion

The frictional factor for the entry is 0.0028 Ns^2/m^4 (for smooth pipe), the entry cross section 0.899 m^2, entry perimeter 3.36 m and the modelled pillar maintained a fixed length, as well as the diameter of the duct 1.07 m while other parameters like the air volume, length of road way and the pillar width were varied. The design for the pre-ventilation system of the Okaba Coal deposit requires 145 m^3/s of air with a main fan pressure of 2.73 kPa and four booster fans of air volume, 110 m^3/s, 125 m^3/s, 95 m^3/s, 105 m^3/s whose fan pressure are 0.63 kPa, 0.87 kPa, 0.47 kPa, 0.50 kPa respectively with exhaust fan of 70 m^3/s at fan pressure of 0.38 kPa, which is required to ventilate the mine. From Fig. 4, as fresh air enters the system through the intake shaft to the surface, it flows along the intake airways to the working areas via the booster fans where the majority of the pollutants may be added to the air such as dust and a combination of many other hazards, such as toxic or flammable gases, heat, humidity and radiation. The contaminated air passes back through the system and then returns airways. The returned (contaminated) air eventually passes back to the surface along the return shaft. Air always flows through the path with least resistance which is needed by the mine fans.

Conclusions

As part of comprehensive study, a model for the calculation of mine airflow distribution (ventilation parameters) has been developed and verified to apply to underground coal mine of Okaba Coal deposit. That are air pressure, fan power and airflow rate have been calculated to maintain the safety levels of methane level in underground mines for workers protection against harmful substances. The result generated has been evaluated and compared with similar studies, which good agreement has been demonstrated.

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